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# VLA High Resolution 1.4 and 8.4 GHz Mapping of the Barred Galaxy NGC 3367

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## ABSTRACT

We report new radio continuum observations with an angular resolution of $2''.1$ at 1.4 GHz (20 cm) and $0''.28$ at 8.4 GHz (3.6 cm), of the barred galaxy NGC 3367. In the map at 1.4 GHz, the central nuclear region connects to the SW lobe, with a projected structure of at a position angle of P.A.$\sim 230°$, forming a jet-like structure. The map at 8.4 GHz shows a compact unresolved source (smaller than 65 pc in diameter) associated with emission from the nucleus and several compact sources located within a radius of about 300 pc, forming a circumnuclear structure. The compact core, jet, and lobes form a small, low-power counterpart to radio galaxies, with a flow axis that is out of the plane of the galaxy. The flow axis (P.A.$\sim 230°$) coincides with the P.A. of the major axis of the galaxy and is thus inclined to the rotation axis of the disk. In addition, the flow axis differs by about 20° from the major axis of the stellar bar. Assuming that the stellar bar rotates counterclockwise (ie. assuming trailing spiral arms), this difference in angle is taken as an argument in favor of having the jet-like structure out of the plane of the disk and not associated with the stellar bar.



*Subject headings:* galaxies: clusters: individual NGC 3367 — galaxies: starburst— galaxies: jets — galaxies: radio emission — (galaxies:) interstellar medium

## 1. Introduction

Strong radio continuum emitters, such as radio galaxies or quasars, are identified with elliptical galaxies and recent mergers, and many of them have impressive radio jets with sizes larger than the host galaxy (see Wilson & Colbert 1995). Maps of radio galaxies display fairly straight radio jets with distant lobes, showing the interaction of the jet with the ambient medium and indicating that the jet axis has been stable for thousands or even millions of years. Recent work indicates the presence of lobes at a distance of hundred kiloparsecs from a spiral galaxy in a cluster (Ledlow, Owen & Keel 1998, Ledlow et al. 2001). In normal spiral galaxies, on the other hand, most of the radio continuum emission comes from the disk component (Hummel 1981, Condon 1987, Garcia-Barreto et al. 1993, Niklas, Klein & Wielebinski 1997). Radio surveys of Seyfert galaxies indicate that the radio continuum emission arises mainly from three components: (1) subkiloparsec emission from the nuclear region; (2) extranuclear kpc scale emission; and (3) greater than kpc-scale emission associated with the disk (Wilson & Ulvestad 1983, Ulvestad & Wilson 1984, Baum et al., 1993, Colbert et al., 1996, Ho & Ulvestad 2001). In barred spiral galaxies, the radio continuum emission is found from the following: (1) emission from the compact nucleus; (2) emission from circumnuclear region ($\leq$ 1kpc); (3) emission from dust lanes in leading side of the stellar bar; and (4) emission from spirals arms and disk (Hummel, van der Hulst & Keel 1987, Condon 1987, Garcia-Barreto et al. 1991a, Garcia-Barreto et al. 1991b, Lindblad 1999, Beck et al. 1999). Depending on the central activity, a spiral can be classified as a starburst or an active galaxy. Seyfert galaxies are stronger radio emitters at 1.4 GHz than normal and barred spirals (Condon 1987). The central radio sources are sometimes associated with a pair of extended sources identified as lobes (Ulvestad & Wilson 1984, Ulvestad, Neff & Wilson 1987, Baum et al., 1993, Colbert et al., 1996, Ho & Ulvestad 2001). These triple sources (compact nucleus plus lobes) are thought to be small scale, low power versions of the large scale jets and lobes seen in radio galaxies and quasars. The radio continuum emission from the central region of spirals is either linked to star formation, via HII regions and supernova remnants as in starbursts, or to an unresolved compact object, probably an AGN (Baum et al 1993). The study of NGC 3367 may be important in order to understand the lobe-central source relationship and help to clarify the starburst-AGN dichotomy.

The barred spiral, NGC 3367, is a mildly active galaxy, between a weak Liner and a HII nucleus (Véron, Gonçalves & Véron-Cetty 1997, Ho et al. 1997) that displays such a triple source structure. At $15''$ angular resolution, in addition to extended emission from different locations in the disk, it shows an unresolved radio source in the center plus two sources in opposite directions from it (Condon et al. 1990). Maps at $4''.5$ resolution indicated more clearly the presence of the two lobes, (Garcia-Barreto et al. 1998). The central source was not resolved at this $4''.5$ angular resolution, and it was unclear if it is a point-like source or an extended circumnuclear structure, and whether or not it is really connected with the lobes.

In this paper we present new VLA[1] radio continuum observations of NGC 3367 at 1.4 GHz with a beam of $\approx 2''.1$, and at 8.4 GHz with a beam of $\approx 0''.28$. §2 presents the observed properties of NGC 3367, §3 presents the new radio continuum observations and

[1]The VLA is part of the National Radio Astronomy Observatory which is a facility of the National Science Foundation operated under agreement by Associated Universities Inc.

results, and §4 gives the discussion and conclusions.

## 2. NGC 3367

NGC 3367 is an SBc(s) barred spiral galaxy with a stellar bar structure of diameter $\approx 32''$ (6.7 kpc) oriented at a position angle (PA) $\approx 70°$. The disk of NGC 3367 is inclined with respect to the plane of the sky at an angle between 6° (Grosbøl 1985) and 30° (Garcia-Barreto & Rosado 2001), and has an optically bright SW structure resembling a half-ring, or a large scale "bow shock", at about 10 kpc from the nucleus. This structure is formed by a collection of H$\alpha$ regions, that looks like a necklace and its origin has been ascribed to an off-center impact with an external intruder, most likely a small galaxy (Garcia-Barreto, Franco & Carrillo 1996). Indeed, the general arrangement of the H$\alpha$ knots is similar to the elongated rings found in numerical simulations of off-center galaxy collisions by Gerber & Lamb (1994). The expanding density wave created by the collision can trigger the formation of the half-ring of HII regions and, given that the expected wave velocity in the disk is below 100 km/s, the collision probably ocurred a few times $10^8$ yr ago. In addition, aside from the radial gas inflows induced by the stellar bar, a galactic collision is also able to drive gas towards the galactic center inducing circumnuclear star formation as well as nuclear activity. NGC 3367 also shows H$\alpha$ emission from the central region with an unresolved source, most likely, a combination of emission from a compact source and circumnuclear structure at a radius of less than 500 pc (Garcia-Barreto, Franco & Carrillo 1996, Garcia-Barreto et al. 1996).

The disk of NGC 3367 has a normal content of atomic hydrogen, with $M_{HI} \sim 7 \times 10^9$ $M_\odot$ (Huchtmeier & Seiradakis 1985), and it is considered an isolated field galaxy, behind the Leo group of galaxies at a distance of 43.6 Mpc, with its closest neighbor more than 900 kpc away to the NE (Tully 1988). Its optical spectrum shows moderately broad H$\alpha$+[NII] lines with FWHM$\sim$ 650 km s$^{-1}$, but H$\beta$ is stronger than [OIII]$\lambda$5007Å and there is weak emission of He II $\lambda$4686Å, suggesting the existence of WR stars and weak Liner activity (Véron-Cetty & Véron 1986, Véron, Gonçalves & Véron-Cetty 1997, Ho et al. 1997). In addition, its X ray luminosity is stronger than that of any normal spiral galaxy, but weaker than Seyfert or radio galaxies (Gioia et al. 1990, Stocke et al. 1991, Fabbiano, Kim & Trinchieri 1992). Nonetheless, from the optical line ratios, NGC 3367 is also considered to have an HII nucleus (Ho et al. 1997).

The first radio continuum observation of the region around NGC 3367 was at 178 MHz, with several arcmin angular resolution (Gower, Scott & Wills 1967). Although the radio emission was identified with NGC 3367 (Caswell & Wills 1967), the bulk of the emission most likely originated from a radio galaxy $\approx 3'$ north of NGC 3367, detected later with better angular resolution (Lawrence et al. 1983). Similarly, observations from Arecibo at 430 MHz and 835 MHz with integrated fluxes of 583 mJy and 365 mJy respectively with $\approx 9'$ angular resolution most likely included the flux of the background radio galaxy (Israel & van der Hulst 1983). Green Bank single dish observations of NGC 3367 at 5 GHz with a resolution of $\sim 3'$ were carried out by Sramek (1975) and Bennett et al. (1986) with integrated fluxes of 35 mJy and 71 mJy respectively. Israel & van der Hulst (1983) reported an integrated flux of 18 mJy at 10.7 GHz with an angular resolution of $3'$ from OVRO 40m. Finally Dunne et al. (2000) reported a flux of 132 mJy at 350 GHz with $15''$ angular resolution.

The first aperture synthesis map of NGC 3367 at 1.49 GHz, with 15″ angular resolution, showed diffuse disk emission plus three peaks aligned in the NE – SW direction (Condon et al. 1990), and the disk emission was noticed to be edge brightened. A more recent mapping at this same frequency, but now with 4.″5 angular resolution, shows more clearly the emission from the triple source: emission from the nuclear region in addition to emission from two extended lobes at a distance of $\sim 6$ kpc from the center (Garcia-Barreto et al. 1998). The polarization analysis indicated that only the SW lobe is polarized, suggesting that it is out of the disk of the galaxy and closer to the observer than the NE lobe (the emission of the NE lobe has been depolarized because this emission has passed through the plane of the galaxy)(Garcia-Barreto et al. 1998). These observations showed very clearly the presence of kiloparsec scale lobes from a barred spiral galaxy seen almost face on, in addition to the weaker emission from a large number of compact sources in the disk.

## 3. Observations & Results

We have carried out radio continuum observations at the VLA in New Mexico in the A array at 1.3851 GHz, 1.4649 GHz, 8.4351 GHz and 8.4851 GHz in 1998 April 23, using 27 antennas with 50 MHz bandwidths, and $\approx 3^h$ integration time at 1.4 GHz and $\approx 4^h$ at 8.4 GHz on NGC 3367. We observed 3C286 as the amplitude and polarization calibrator and 1120+143 as the phase calibrator at 1.4 GHz and 1051+213 as the phase calibrator at 8.4 GHz. We adopted a flux density of 3C286 of $S_\nu = 14.554$ Jy at $\nu = 1.4649$ GHz, and $S_\nu = 5.1702$ Jy at $\nu = 8.4851$ GHz. Several iterations of phase self-calibration were used at 1.4 GHz. No self-calibration was used at 8.4 GHz because the peak emission was only $\approx 1$ mJy beam$^{-1}$.

### 3.1. The Jets and the SW Lobe

Figure 1 shows the total intensity map at 1.4 GHz of NGC 3367 with a full width at half maximum (FWHM) angular resolution beam of 2.″1 × 1″.8 at a P.A.$\approx -67°$ and an rms noise of $\sim 25$ $\mu$Jy beam$^{-1}$. The emission above the $2\sigma$ level clearly shows the central source and lobes. The central source has a peak emission of 11.2 mJy beam$^{-1}$ and is still unresolved. At the $2\sigma$ level, there is no clear connection of the central source and the SW lobe. There are, however, extensions pointing toward the NE and SW lobes, and a faint connection appears at about $1\sigma$ (see below). At this new higher angular resolution 1.4 GHz observation, the emission from the lobes starts to be resolved, and the SW lobe shows the same polarization (not shown here) as in the previous 4″.5 angular resolution observations, namely that the eastern side of the lobe shows the strongest polarization (Garcia-Barreto et al. 1998).

The emission from both lobes is mostly diffuse, with some clumpy structure. The morphology of the SW lobe resembles a bow shock, probably due to the interaction of a relativistic jet with a low density ambient medium. There is faint emission directed from the central radio source towards the SW lobe, indicating that they are connected through a low surface brightness continuous structure, 7″ × 4″ (2.5 kpc × 850 pc), perhaps jet-like. The width is probably an upper limit dictated by the restoring beam size. This is seen in Figure 2, which shows the faint emission from the innermost 25″ central region of NGC 3367 at 1.4 GHz. The contours are drawn starting at a $1\sigma$ level, and shows that the central

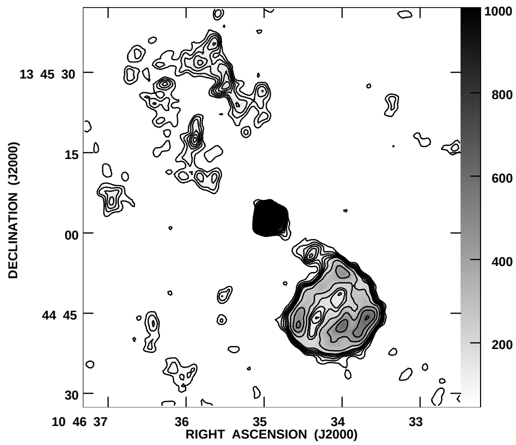


Fig. 1.— Radio continuum emission from NGC 3367 at 1.4 GHz with a beam FWHM$\approx$ $2''.1 \times 1''.8$ at PA$\approx -67°$. The contours are in units of 25$\mu$Jy/beam and the levels are 2, 3, 4, 5, 6, 7, 10, 15, 20, 25, 30, 50, 65, 80, and 120. The weak sources outside the area of the central region plus lobes are real and belong to emission from the disk, as can be seen in lower resolution maps shown in Figures 2 and 6 of Garcia-Barreto et al. (1998). Greyscale is from 50 $\mu$Jy/beam to 1 mJy/beam

emission indeed connects to the SW lobe. Although in Figure 2 there is a minimum of emission midway (ie. $\alpha \approx 34^s.6; \delta \approx 44'\ 59''$) the $1\sigma$ contour surrounds this minimum and connects the central radio emission with the SW lobe; in order to verify the existence of the structure, we did make several maps with different restoring beams with self calibration of phase and amplitude and the structure was there in all maps although with slightly different detailed morphology (not shown here). Therefore we feel confident that the structure connecting the central radio emission and the SW lobe really exists; however, the detailed morphology needs to be taken with caution. The average P.A.$_{rad}$ of this structure is $\sim 230°$ with a spread of $\pm 10°$. The NE extension of the central radio source is seen clearly at a P.A. $\sim 35°$, and seems to be the starting part of the counter jet that flows towards the NE lobe. The stellar bar, however, is oriented at P.A.$_{bar} \sim 245° \pm 5°$. In the SW, the radio extension lies to the south of the optical bar, while in the NE, the radio extension lies to the north of the bar (see Figure 3). There is no radio continuum emission (at the three sigma level of the rms noise) from any dust lane in the leading side of the stellar bar, as is often detected in other barred galaxies (Ondrechen & van der Hulst 1983, Beck et al. 1999). The fact that the SW lobe is out of the plane of the galaxy suggests that the relative alignment between the radio structure (connecting the central radio source and the SW lobe) and the stellar bar may be only a projection of the structure onto the galaxy disk and that the structure is out of the plane of the galaxy disk.

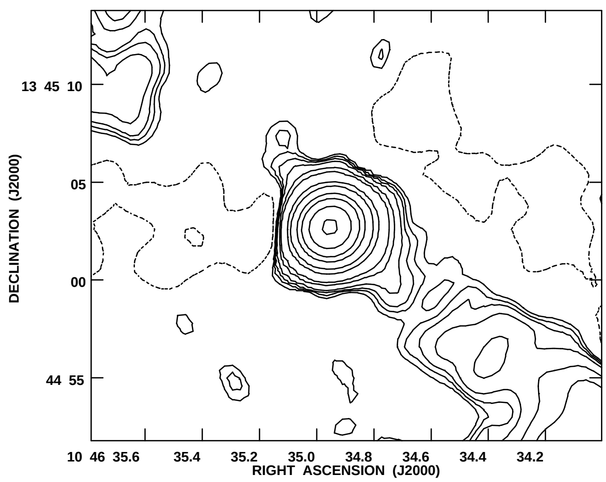


Fig. 2.— Radio continuum emission from the innermost central region at 1.4 GHz from Figure 1. The position angle (P.A.) of the radio continuum emission connecting the central source with the south west (SW) lobe is P.A.$_{rad}$ $\sim$ 230° $\pm$ 10°; the stellar bar P.A. is P.A.$_{bar}$ $\sim$ 245° $\pm$ 5°; the approaching semi major kinematical axis is P.A.$_{ma}$ = 231°. The contours are in units of 25$\mu$Jy/beam and the levels are -2, 1, 1.5, 2, 3, 6, 10, 30, 50, 100, 150, 250 and 410. The second negative contour left of the central emission only indicates a relative maximum ($\approx -40\mu$Jy/beam) and not a deeper region.

### 3.2. Compact Nucleus and Circumnuclear Structure

Figure 4 shows the radio continuum contours of the emission from the innermost 4$''$ central region of the galaxy at 8.4 GHz, with an angular resolution of 0$''$.28 $\times$ 0$''$.25 at a P.A.$\sim$ 1° and an rms noise of 11$\mu$Jy beam$^{-1}$. The emission is dominated by a still unresolved central source of 0.96 mJy beam$^{-1}$, at $\alpha(J2000) = 10^h46^m34^s.956$ $\delta(J2000) = +13°45'02''.94$. Its deconvolved diameter is less than 65 pc, and is surrounded by several low surface brightness peaks of emission out to a distance of $\approx$ 300 pc. A rather similar structure is found in the lower resolution map at 1.4 GHz when a central unresolved source is subtracted. At 8.4 GHz, there is a short extension at a PA of 230°, the same as seen for the jet on larger scales. No polarization is detected at 8.4 GHz, with an upper limit of 2 % for the compact nucleus, and a characteristic limit of 25 % for the circumnuclear structure. Peak fluxes at various positions in the circumnuclear region are all smaller than 100$\mu$Jy beam$^{-1}$.

Figure 5 shows the innermost 10$''$ central radio continuum with a superposition of the 1.4 GHz (in contours) and the 8.4 GHz (in greyscale) emissions. The emission is clearly dominated by the central source and an estimate of the spectral index between 1.4 GHz and 8.4 GHz (integrated over the central 3.5$''$) gives $\alpha \sim -0.53$ ($S_\nu \propto \nu^\alpha$), indicating that the radiation is mainly synchrotron emission. The interpretation of spectral index should be taken with caution since the fluxes are the sum of the core plus the circumnuclear sources. The total flux at 1.4 GHz within 7$''$ is 16.8 mJy, while the total flux at 8.4 GHz within 4$''$.5 is 5.4 mJy.

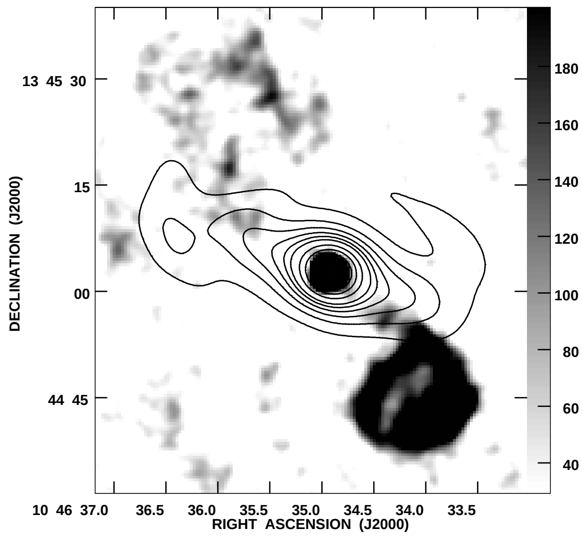


Fig. 3.— Radio continuum emission at 1.4 GHz, in greyscale and the optical continuum (I broadband filter centered at $\lambda$8040 Å ) in contours. The contours are in arbitrary units relative to peak showing mainly the bright emission from the central stellar bar.

## 4. Discussion

We have observed the radio continuum emission from the barred galaxy NGC 3367, with the VLA A array, at 1.4 GHz and 8.4 GHz with $2''.1$ and $0''.28$ spatial resolutions, respectively. The radio maps show emission from the central region, the lobes, and a weak jet. This morphology in NGC 3367 resembles the morphology of more powerful radio galaxies (Faranoff & Riley 1974, Schilizzi et al. 2001). The power at 1.4 GHz is two to three orders of magnitude less than any radio galaxy and it is more like the power of Seyfert galaxies, see Table 1 (see Figure 3 of Ho & Ulvestad 2001, Ulvestad & Ho 2001). Nonetheless this is one of the largest and best defined triple source ever detected in a galaxy considered to be a normal barred spiral. The triple source is due to emission from the central sources, emission from a jet-like structure connecting the central emission with the lobes and the extended lobes. Other large radio structures have been observed in the Seyfert galaxies , for example, Mrk 6 (lobe extent 14 kpc), Mrk 348 (lobe extent 5 kpc), NGC 3516 (lobe extent 8.5 kpc) (Baum et al., 1993), NGC 4235 (lobe extent 9 kpc) (Colbert et al., 1996) and in the disk galaxy O313-192 in the cluster A428 (lobe extent 100 kpc) (Ledlow, Owen & Keel 1998, Ledlow et al. 2001). The radio continuum jets in other barred galaxies as NGC 1068 (Wilson & Ulvestad 1987) and NGC 5728 (Schommer et al. 1988) are much smaller in size (of the order of tens to hundred parsecs). In contrast with O313-192, which has an AGN, and the Markarian galaxies, which are Seyfert 1s and 2s, NGC 3367 is only a mildly active Liner and, based on optical line emission ratios and widths, is not even considered to be a Seyfert galaxy.

The P.A.$_{jet}$ of the jet-like structure ($\sim 230° \pm 10°$; see Figure 3) is the same as the

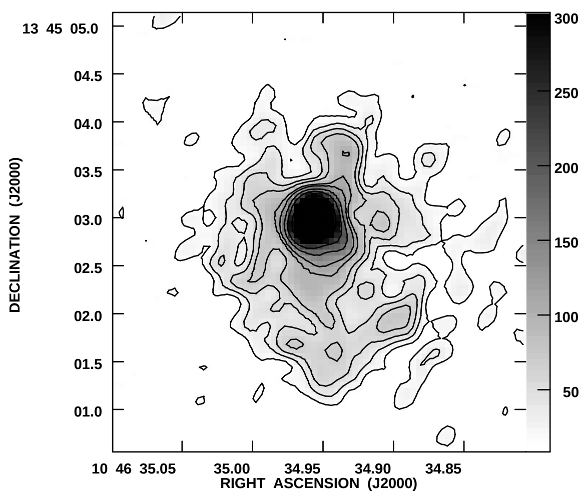


Fig. 4.— Radio continuum emission from the innermost central region at 8.4 GHz. The restoring beam FWHM is $0''.28 \times 0''.25$ ($\sim 60$ pc). The contours are in units of $11\mu$Jy/beam and the levels are -3, 1.5, 3, 4.5, 6, 9, 11, 15, 20, 30, 40, 60, 80 and 100. Greyscale is from 11 to 300 $\mu$Jy beam$^{-1}$.

P.A.$_{ma}$ of the major axis, as determined from H$\alpha$ kinematics (Garcia-Barreto & Rosado 2001). The jet would be considered a low power one (Massaglia, Bodo & Ferrari 1996). The direction of the plasma outflow is thus not aligned with the rotation axis of the disk because, if that were the case, the relative orientation of the lobes, in NGC 3367, would have to lie closer to the direction SE-NW, that is, the projection of the P.A. of the minor axis as expected in the very simple picture that jets emanating from an active nucleus would emerge at right angles to the disk of the host galaxies (Kinney et al. 2000). However the simple scenario is contradicted by the observations of Seyfert galaxies (Schmitt et al. 1997, Kinney et al. 2000, Ulvestad & Ho 2001). Our observations of NGC 3367 suggest that the outflow axis is inclined with respect to the rotation axis of the galaxy and also inclined to the line of sight. A comparison between the the P.A. of the extended radio structures from Seyferts with their host galaxies' major-axis P.A. indicate that the radio structures in type-2 Seyferts are oriented along any direction in the galaxy, and not necessarily along the minor axis (Schmitt et al. 1997, Kinney et al. 2000, Ulvestad & Ho 2001). The directions of the radio jets are consistent with being completely uncorrelated with the planes of the host galaxies (Pringle et al. 1999, Nagar & Wilson 1999, Kinney et al. 2000). Our observations indicate that NGC 3367 (being a noninteracting late-type Liner/HII spiral having kpc lobes) presents P.A$_{radio}$ $\approx$P.A$_{maj}$.

The emission at 8.4 GHz, with the higher resolution, is complex and shows an unresolved nuclear source and several sources surrounding it. The circumnuclear radio sources are at all position angles (see Figs. 4 and 5), and do not align at all with the lobes or with any other optical structure in the galaxy. This implies that the circumnuclear sources are probably located in the plane of the disk, and might be identified with a circumnuclear structure at distances of 125 pc to 325 pc. The radio emission from the inner

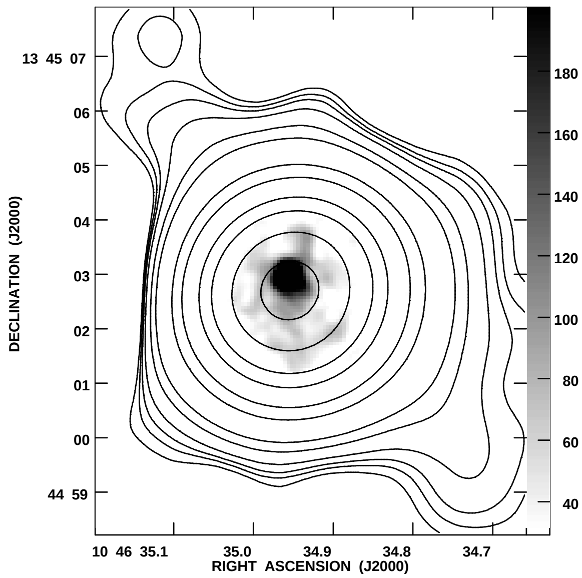


Fig. 5.— Radio continuum emission from the innermost central region at 1.4 GHz, in contours, and at 8.4 GHz, in greyscale. The contours are in units of 25$\mu$Jy/beam and the levels are 1, 1.5, 2, 3, 6, 10, 30, 50, 100, 150, 250 and 390. The greyscale is from 30$\mu$Jy/beam to 200$\mu$Jy/beam.

$4''.5$ is then most likely a mixture of synchrotron and free-free emission and the sources are most probably giant HII regions near an inner Lindblad resonance (as it is the case in other barred galaxies).

An additional hint for the existence of a circumnuclear structure is provided by the H$\alpha$ emission. As mentioned earlier NGC 3367 shows H$\alpha$ emission from the central region which is unresolved from ground observations (Garcia-Barreto, Franco & Carrillo 1996, Garcia-Barreto et al. 1996) with a bright emission from a compact source and weak extended emission from within $6''$. Assuming that the peak of H$\alpha$ coincides with the peak of the 8.4 GHz radio continuum emission, we then have subtracted the 8.4 GHz radio continuum emission from the H$\alpha$ emission in such a way as to have zero emission from the center. The image, H$\alpha$ - 8.4 GHz radio continuum, that is produced is shown in Figure 6; it shows an H$\alpha$ circumnuclear structure. This H$\alpha$ image provides *no* proof of the existence of a circumnuclear structure since we have made several assumptions: (1) that the spatial position of peak of the H$\alpha$ emission coincides with the position of the 8.4 GHz emission; (2) that the radio continuum 8.4 GHz is related to the H$\alpha$ emission in such a way that they are directly proportional to each other through a constant; (3) that the constant of proportionality was chosen in such a way as to have zero emission from the very center; (4) that the final subtracted image represents emission from the disk of the galaxy where we think the structure lies (near a ILR). The image however is very suggestive of the existence of such a structure. If the circumnuclear structure represents regions of massive

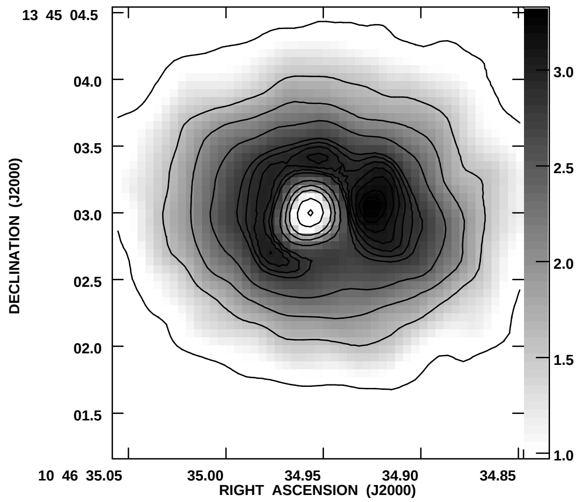


Fig. 6.— Hα - 8.4 GHz emission from the innermost 4″. The contours and greyscale are in arbitrary units relative to the maximum. The structure observed indeed suggests the existence of a circumnuclear structure within the innermost 300 pc (1″ = 210 pc). This image was obtained with several assumptions, among them are (1) the spatial location of the peak of the Hα emission coincides with the spatial location of the 8.4 GHz emission; (2) both, the peaks of Hα and 8.4 GHz emissions are directly proportional to each other; (3) the constant of proportionality was chosen as to have zero emission from the center. Although the assumptions seem reasonable, the structure is definitely not a proof, but it is very suggestive, of the existence of a circumnuclear structure in Hα.

star formation one could estimate the rate of supernova using the relation (Condon 1992):

$$\frac{\nu_{SN}}{yr^{-1}} \sim \frac{L_N/(10^{22} W Hz^{-1})}{13(\nu/GHz)^{-\alpha}} \tag{1}$$

using the integrated flux within the innermost 3″.5 at 1.4 GHz and assuming that all of this emission is of non-thermal origin (which we know is wrong but hope that not by much) and a spectral index $\alpha = -0.53$ then the expected supernova rate in the circumnuclear region of NGC 3367 is $\nu_{SN} = 0.03$, which is very similar for other galaxies (Condon 1992). The global star formation rate using the far infrared (*IRAS*) luminosity and using the relation (Condon 1992):

$$\frac{SFR(M \geq 5M_{\odot})}{M_{\odot} yr^{-1}} \sim \frac{L_{FIR}/L_{\odot}}{1.1 \times 10^{10}} \tag{2}$$

with a $L_{FIR} = 2 \times 10^{10} L_{\odot}$ (Soifer et al. 1989) we get $SFR_{NGC3367} \sim 1.8 M_{\odot}\ yr^{-1}$ a value which similar to the values found in other galaxies (Condon 1992).

As stated above, the gas in the circumnuclear structure could have been driven inwards either by the perturbations induced by the potential of the stellar bar, or by a possible off-center collision with a minor intruder. A reason in favor of the active compact radio nucleus is the short extension in the 8.4 GHz map that has a P.A. similar to that of the jet-like structure observed in the 1.4 GHz map that connects the central radio source with the SW lobe. If the flow were coming from a starburst wind (originating from the circumnuclear structure), this wind would be directed (in the most simple case) out of the plane towards the rotation axis of the disk, (where the density gradient is largest) and the jet - like and lobes would be projected in the SE - NW direction as mentioned above. Therefore, although an elongated structure is not observed at 8.4 GHz forming a jet, the observations suggest that the plasma flows out from the compact nucleus, possibly directed in the observed orientation as a result of an accretion disk inclined (but not perpendicular) with respect to the plane of the galaxy. One thus could infer that the jet does not interact with the circumnuclear material. The interpretation of the origin of the energy for the jets, in NGC 3367, might still controversial in the following respect, namely, the global q parameter. The q parameter is the ratio of the FIR (*IRAS*) emission to the 1.4 GHz emission (Helou, Soifer & Rowan-Robinson 1985). Empirically the median $2.2 \leq \langle q \rangle \leq 3.1$ was found for spiral galaxies (Condon, Anderson & Broderick 1995), while $\langle q \rangle \leq 2$ was found for galaxies powered by an AGN (Condon, Frayer & Broderick 1991). In particular, based on the value found for q for NGC 3367 (q= 2.4 using the 5 GHz total emission) it was concluded that the dominant energy source in NGC 3367 is stars (Condon, Frayer & Broderick 1991, Condon, Anderson & Broderick 1995). If we compute q using the total emission at 1.4 GHz (119 mJy [Condon et al. 1998]), we get is q=1.9 which might indicate the presence of an (mildly) AGN according to the convention (Condon, Frayer & Broderick 1991, Condon, Anderson & Broderick 1995). We believe that this result involves global emissions (radio and infrared) and not necessarily the energy powering the jets and lobes observed in NGC 3367 (Condon, Frayer & Broderick 1991, Condon, Anderson & Broderick 1995). This result still needs to be confronted with the current observations of the central radio sources, jet and lobes in NGC 3367.

This central radio continuum structure (compact source with circumnuclear regions) is very similar to the structure observed in some barred Sy 1 galaxies, like NGC 1097 (Hummel, van der Hulst & Keel 1987) and NGC 7469 (Condon & Broderick 1991, Wilson et al. 1991, Miles, Houck & Hayward 1994, Mauder et al. 1994, Genzel et al. 1995). The radius of the circumnuclear structure in NGC 1097 is about 550 pc (Hummel, van der Hulst & Keel 1987), and about 450 pc in NGC 7469 (Condon et al. 1991). These are similar to the one observed in NGC 3367 ($\sim$ 300 pc). None of these Seyfert galaxies, however, show any indication of a large scale jet or radio continuum extended lobes (Hummel, van der Hulst & Keel 1987, Wilson et al. 1991). In the case of normal barred galaxies, like NGC 1326 and NGC 4314, they show H$\alpha$ circumnuclear structures with radio continuum emission characteristic from regions of star formation at similar radii (400 pc and 325 pc, respectively). None of them have radio continuum emission from the compact nucleus (Garcia-Barreto et al. 1991a, Garcia-Barreto et al. 1991b) nor any radio continuum extended lobes. These differences in radio continuum emission morphology from barred galaxies probably suggest also differences in disk properties, like the amount of gas in the disk, the strength of the gravitational potential including the non-axisymmetric component, and possibly different ways of transporting material to the central regions and compact nucleus.

Our main results are as follows:

1) There is a faint structure that connects the central source with the SW lobe, here identified as a low surface brightness jet. Thus, the lobes are currently being fed by plasma from the compact radio source.

2) At the highest resolution, the 8.4 GHz emission shows an unresolved central peak with several circumnuclear sources. The unresolved source, which is located at the center of the galaxy, is $\sim$ 10 times stronger than individual peaks of emission in the circumnuclear region, and its deconvolved diameter is smaller than 65 pc.

3) The circumnuclear radio sources are most likely not associated with the interaction of the jet and the sourrounding medium.

4) An estimate of the spectral index from the innermost region within $3''.5$ is about -0.53.

5) The flow of plasma from the nuclear region to the lobes is out of the plane of the galaxy but inclined with respect to the rotation axis of the disk.

6) No emission is detected from the stellar bar.

Our high resolution imaging has confirmed ideas from earlier work that NGC3367 is a currently active low power radio galaxy, continuing to be powered by a weak Liner/HII nucleus. Like other barred spirals, it shows indications of star formation both in the center and on larger scales. The jet-like structure connecting the central source with the SW lobe is out of the plane of the disk.

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Table 1: Radio Continuum Observations of NGC 3367

| Frequency | Structure | Flux (mJy) | log (P/W Hz$^{-1}$) | Resolution | References |
|---|---|---|---|---|---|
| 1490 MHz | Center | 18.40[a] | 21.6 | $15''.0$ | 1 |
| 1490 MHz | SW lobe | 14.70[a] | 21.5 | $15''.0$ | 1 |
| 1425 MHz | Center | 15.80[a] | 21.5 | $4''.5$ | 2 |
| 1425 MHz | Triple | 51.50[b] | 22.0 | $4''.5$ | 2 |
| 1425 MHz | Center | 11.20[a] | 21.4 | $2''.1$ | 3 |
| 1425 MHz | Center | 13.10[c] | 21.5 | $2''.1$ | 3 |
| 1425 MHz | Center | 16.80[d] | 21.6 | $2''.1$ | 3 |
| 8460 MHz | Center | 0.96[a] | 20.3 | $0''.3$ | 3 |
| 8460 MHz | Center | 0.96[e] | 20.5 | $0''.3$ | 3 |
| 8460 MHz | Center | 5.1[c] | 21.0 | $0''.3$ | 3 |
| 8460 MHz | Center | 5.4[f] | 21.1 | $0''.3$ | 3 |

[a] Peak flux.
[b] Peak flux from center plus integrated fluxes from lobes.
[c] Integrated flux from inner $3''.5$
[d] Integrated flux from inner $7''$.
[4] Integrated flux from inner $0''.5$.
[f] Integrated flux from inner $4''.5$
References: (1)Condon et al. 1990; (2) Garcia-Barreto et al. 1998; (3) This work